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Effects of inert gas narcosis on rehearsal strategy in a learning task

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Fowler B, Hendriks P, Porlier G. Effects of inert gas narcosis on rehearsal strategy in a learning task. Undersea Biomed Res 1987; 14(6):469–476.—Two experiments were conducted to examine the effects of 35% nitrous oxide (N_2O) on rehearsal strategy while learning a list of words in a free-recall paradigm. In experiment 1, the subjects learned the list while rehearsing the words aloud. Learning was slowed and an analysis of the recorded rehearsal protocols revealed a decrease in the overall rate of rehearsal. In addition, there was a decrease in both the number of words rehearsed together and the proportion of words rehearsed from earlier serial positions in the list. In experiment 2, the subjects were required to follow a different rehearsal protocol which was identical for both N_2O and the air-breathing control. They had no difficulty following this protocol, but learning was still slowed. These results demonstrate that rehearsal strategies may be modified by narcosis but can be manipulated experimentally. This is consistent with the hypothesis that strategic variables play an important role in the slowed processing model of inert gas narcosis.

inert gas narcosis
learning
rehearsal strategy

The slowed processing model has been proposed as an explanation for the behavioral effects of inert gas narcosis. This model and its conceptual basis in the information processing approach to skilled performance have recently been the subject of an extensive review by Fowler et al. (1). Briefly, the information-processing approach assumes a tripartite division of factors controlling performance into functional, structural, and strategic variables. The primary effect of narcosis is considered to be a decrease in arousal, a functional variable, thereby producing a slowing of information processing throughout the structural stages of the system (2–4). However, strategic variables also play an important role in determining performance under narcosis, and it is this class of variables that is the focus of the 2 experiments reported in this paper.

Strategic variables are analogous to the software in a computer. They control the manner in which a performer organizes information-processing resources to perform

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a task and include the distribution of attention, speed-accuracy trade-off settings, decision criteria, and rehearsal strategies (5). The strategy used to perform a task is likely to change under narcosis, but such changes are considered to be secondary to slowing, i.e., as a compensatory response to slowing or in reaction to euphoria (1). The role of strategic variables is important because they provide a mechanism for explaining the apparently complex effects of narcosis on performance. In this view, the slowing component of narcosis will be expressed as a particular behavioral pattern (5) according to the strategy adopted by the performer. In turn, strategy will be influenced by such factors as the nature of the task, goals concerning performance on the task, and degree of experience with narcosis. To take a simple example, many mental-arithmetic tests use both completion time and number of items correct as dependent measures. The effects of narcosis on this task may appear very different, depending on whether the experimenter controls accuracy or allows it to vary by letting the performers shift their settings on the speed-accuracy trade-off function (1). Clearly, the slowed processing model predicts that changes in strategy may not be a necessary concomitant of narcosis and should be open to experimental manipulation. A corollary is that strategies must be strictly controlled if the underlying slowing of narcosis is to be revealed clearly.

Support for the view outlined above comes from studies demonstrating that the strategies of narcotized performers can be controlled experimentally. It has been observed that the accuracy of auditory (6) and visual (2) attention can be maintained and that speed-accuracy trade-off settings can be held constant so that accuracy is not traded for speed, a typical effect of narcosis (2, 7). The two experiments reported here extend this work to rehearsal strategies that refer to a process whereby acoustic information is recycled, either overtly or covertly, with the object of maintaining information in short-term store and encoding it into long-term store (8). The purpose of these experiments was to observe whether narcosis changed the rehearsal strategy used to learn a list of words (experiment 1) and to determine whether this change could be brought under experimental control (experiment 2).

METHODS

Subjects

Seven male and 5 female, paid volunteers, ranging in age from 22 to 36 yr were used in experiment 1. They gave informed consent and comprised both York University students and staff members from the Defence and Civil Institute of Environmental Medicine. Eight of the subjects from experiment 1 took part in experiment 2.

Apparatus

In both experiments, narcosis was induced with a 35% N_2O:65% O_2 mixture with air as a control. Both breathing mixtures were delivered to the subject from high-pressure bottles via a nonbreathing, oral-nasal mask. Rehearsal strategies were analyzed with a technique in which the subjects rehearse overtly while learning a word list so that the pattern and timing of rehearsals can be observed (9). To-be-learned material consisted of six lists (experiment 1) and three lists (experiment 2) of 30 words

drawn from Thorndike and Lorge (10). The words were between five and eight letters long with frequencies of occurrence greater than five per million. The lists were balanced for starting letter of the alphabet, and proper nouns were excluded. The words in a list were presented one at a time at a fixed rate in upper case on the screen of a computer (Commodore model 2001). After the 30th word, a line of three asterisks appeared at the same rate. The overt rehearsals of the subjects were recorded on one channel of a stereophonic tape recorder (Revox model B-77) by means of a microphone situated in the oral-nasal mask. Computer-generated tone pulses, coincident with the appearance of each word and the line of asterisks, were recorded on the other channel of the tape recorder.

Procedure

In experiment 1, each subject took part in two practice sessions and one experimental session on 3 successive d. In the first two sessions, the subjects practiced with four of the lists in a multitrial, free-recall procedure, breathing both air and N_2O. There were six successive trials with each word being presented in a different random order on each trial at the rate of one word/3 s. The subjects were instructed to say each word aloud at least once after it appeared and to rehearse aloud continually at a rate that they felt would help them to learn the maximum number of words. When the line of asterisks appeared, the subjects wrote down as many words as they could remember over a 3-min period. At the end of this recall period, they were instructed to pay attention to the screen and to begin rehearsing when the first word of the next trial was presented. In the experimental session, the same procedure was followed but a repeated measures design was adopted. Half the subjects were tested in the order air-N_2O and the other half in the reverse order. Each mixture was breathed for 15 min before the commencement of testing. The two experimental lists were counterbalanced between conditions, and each subject was assigned a different list in each condition.

Experiment 2 differed from experiment 1 in a number of respects. The rate of presentation and the pattern of rehearsal were manipulated experimentally by equating these parameters in the air and N_2O conditions. Since there were relatively large individual differences in rehearsal rate, this parameter was individualized and was based on the average of the rehearsal rates for air and N_2O of each subject obtained from experiment 1, the range being 0.92–1.70 s/word. Four trials were given and on every trial each word in the list was presented on the screen 3 times according to the following sequence; 1, 2, 3, 2, 3, 4, 3, 4, 5, ... 30, 1, 2. One of the three lists was used only for practice before the experiment. During practice the subjects were trained to rehearse each word overtly as it was presented.

RESULTS

The mean percentages of words correctly recalled in experiment 1 are presented in Table 1. An analysis of variance for repeated measures consisting of 12 subjects × 2 breathing mixtures × 6 trials indicated that the breathing mixtures ($F1, 11 = 98.8$, $P = <0.001$) and trials ($F5, 55 = 81.0$, $P = <0.001$) factors and the breathing mixtures times trials interaction ($F5, 55 = 22.4$, $P = <0.001$) were all significant.

TABLE 1
MEAN PERCENTAGE OF WORDS CORRECTLY RECALLED AS A FUNCTION OF BREATHING MIXTURE AND TRIALS IN EXPERIMENT 1

	Trials					
Breathing Mixture	1	2	3	4	5	6
Air	27 ± 2*	43 ± 2	56 ± 3	68 ± 3	72 ± 4	76 ± 4
35% N_2O	17 ± 2	26 ± 2	33 ± 3	34 ± 4	40 ± 4	46 ± 4

*SEM.

TABLE 2
MEAN PERCENTAGE OF ERRORS AS A FUNCTION OF BREATHING MIXTURE AND TRIALS IN EXPERIMENT 1

	Trials					
Breathing Mixture	1	2	3	4	5	6
Air	8 ± 4*	9 ± 3	7 ± 2	5 ± 2	4 ± 2	3 ± 1
35% N_2O	10 ± 3	10 ± 4	7 ± 2	5 ± 2	7 ± 2	4 ± 2

*SEM.

These results confirm the usual learning decrement seen with narcosis. Mean percentage of errors (words written down that were not in the list divided by the number of correctly recalled words) can be found in Table 2. Only the trials factor was significant ($F5, 55 = 2.67$, $P = <0.05$), indicating a decrease in percentage of errors as learning progressed but no difference between breathing mixtures.

The rehearsal analyses for experiment 1 were based on 11 subjects because a technical malfunction caused the loss of recorded rehearsals for 1 subject. A rehearsal set (RS) was defined as the time interval between each tone pulse on the tape recording; giving a total of 30 RSs/trial. The overall rate of rehearsal was analyzed by calculating the number of words rehearsed (a rehearsal was the utterance of any word) per RS averaged across the 30 RSs/trial. An analysis of variance with breathing mixtures and trials as factors on this variable revealed that mixtures were significant ($F1, 10 = 36.7$, $P = <0.001$). These results indicate that N_2O reduced the rate of rehearsal (means for air and N_2O, 2.9 ± 0.3 SEM and 2.5 ± 0.2, respectively). Nitrous oxide also reduced the number of different words rehearsed in an RS (mixtures, $F1, 10 = 11.5$, $P = <0.01$; air and N_2O, 2.2 ± 0.2 and 1.9 ± 0.1, respectively). The final effect of N_2O was to reduce the proportion of words from earlier serial positions in the list that was currently being rehearsed. This variable was defined as the proportion of words used in an RS that had appeared seven or more serial positions before the currently displayed word, averaged across the RSs from 8–30 on each trial (mixtures, $F1, 10 = 5.36$, $P < 0.05$; air and N_2O, 0.20 ± 0.05 and 0.14 ± 0.04, respectively). On the other hand, N_2O had no significant effect on the rate of rehearsal of words that were present in an RS. This rate was defined as the ratio of the number of different words in an RS to the number of rehearsals contained therein.

In experiment 2, the verbalizations of each subject followed the defined protocol exactly. Thus, their overt rehearsal strategy was manipulated successfully. Table 3 presents the mean percentages of words correctly recalled. An analysis of variance confirmed that learning was slowed under narcosis since the breathing mixtures ($F1, 7 = 40.2$, $P = <0.001$) and trials ($F3, 21 = 37.7$, $P = <0.001$) factors and the breathing mixtures times trials interaction ($F3, 21 = 18.2$, $P = <0.001$) were all significant.

DISCUSSION

The usual learning deficit associated with narcosis (1) was observed in this study; more importantly, two new findings emerged. Narcosis altered the overt rehearsal strategy of the subjects and these changes could be modified experimentally. In experiment 1, a decrease in the overall rate of rehearsal was found. This seems to reflect a decrease in the number of different words that were rehearsed in an RS, because the rate of rehearsal of individual words remained unchanged. Narcosis also decreased the proportion of words that were rehearsed from the earlier part of the list. This finding is consistent with previous experiments which show that both N_2O (11) and compressed air (12) reduce the recall of words from the early and middle parts, but not the later part, of a word list. Evidence of this kind has been interpreted as support for the view that narcosis disrupts long-term but not short-term memory storage (1, 11).

Experiment 2 demonstrated that it was possible to manipulate the overt rehearsal strategy of a narcotized subject. Further, despite equating strategies across conditions, learning was still disrupted. The differences in learning between the control condition and narcosis on trial 4 of experiments 1 and 2 were 34 and 42%, respectively. These results support the view that, while narcosis may alter the settings of strategic variables, these changes are not inevitable and are open to manipulation (1). The difference in learning in the presence of identical strategies suggests that strategy changes per se cannot account for the learning deficit induced by narcosis. However, this latter conclusion is weakened by the lack of control over covert strategies.

In experiment 2, the subjects were instructed not to rehearse covertly, even if the overt rehearsal strategy seemed inefficient. It cannot be established how closely these instructions were obeyed although all subjects claimed not to have rehearsed covertly. In any event, it seems reasonable to assume that the manner in which overt and

TABLE 3

MEAN PERCENTAGE OF WORDS CORRECTLY RECALLED AS A FUNCTION OF BREATHING MIXTURE AND TRIALS IN EXPERIMENT 2

	Trials			
Breathing Mixture	1	2	3	4
Air	28 ± 2*	48 ± 5	60 ± 7	73 ± 6
35% N_2O	17 ± 2	25 ± 3	28 ± 5	31 ± 7

*SEM.

covert strategies are influenced by narcosis is fundamentally identical and that covert strategies would also be open to manipulation under narcosis.

What interpretation can be put on the changes in rehearsal observed in experiment 1? Rehearsal is regarded as an encoding process that is important to memory and learning (8). The two aspects of rehearsal altered by narcosis point to a reduction in the efficiency of this process because the number of words rehearsed in an RS has been associated with the quality of rehearsal (13, 14), and the proportion of words rehearsed together from earlier in the list associated with the opportunity to strengthen interitem organization (15). This reduction in the efficiency of encoding could be caused by a slowing of information processing, an explanation that is consistent with the decreased overall rehearsal rate. From this point of view, rehearsing fewer words with the rate/word unchanged is a strategy for coping with reduced processing capacity by shedding words held in the short-term store, thus encoding the remainder more adequately. From another point of view, the reduction in efficiency of encoding could be ascribed to an inability to retrieve items from the long-term store. This explanation implies that the subjects were forced to adopt a different strategy because their normal one was unavailable to them. These two explanations represent an unresolved question in narcosis research—whether the disruption of learning and memory is due to input or to retrieval from the long-term store (1).

Although the results of experiment 1 were consistent with the assumption of the slowed processing model that values of strategic variables may shift under narcosis, it is unclear whether this shift was optimal for minimizing the learning deficit or, indeed, whether different strategies would influence the size of the deficit at all. These are important issues for future research which bear on the question of the factors influencing shifts in strategic variables under narcosis. These factors are not well understood at present, but in the case of the speed-accuracy operating characteristic it has been proposed that accuracy decreases under narcosis for two reasons (1). First because performers prefer to distribute the impact of slowing between speed and accuracy, and second because euphoria makes them less ready to maintain a particular setting. There is little doubt that this issue must be addressed if performance under narcosis is to be predicted with any degree of accuracy. This is illustrated in an experiment where the effects of narcosis on working memory (1) were assessed with the missing scan technique at two different rates of stimulus presentation (16, 17). The deficit pattern, measured by response latency and recall accuracy, differed sharply with rate, and it appears that the employment of different processing strategies at each rate played a key role in this difference (1).

The results of these experiments also suggest that narcotized individuals can act in an organized and rational manner and are capable of following instructions, even when complex cognitive processes are involved. This conclusion is not in agreement with the classic description of narcosis provided in current textbooks, which emphasizes the helplessness of narcotized individuals (18). On the other hand, it is consistent with the suggestion that, when divers cannot avoid narcosis, the use of some relatively simple training principles would improve their work effectiveness and safety (19). This line of argument assumes that the results of the present experiments with N_2O can be generalized to nitrogen narcosis. While current evidence strongly favors this assumption (1, 4, 11), it needs to be verified by replicating the present results with hyperbaric air.

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Fowler B, Hendriks P, Porlier G. Effets de la narcose des gaz inertes sur la stratégie de répétition dans une tâche d'apprentissage. Undersea Biomed Res 1987; 14(6):469–476.—Deux expériences furent effectuées pour examiner les effets de 35% de protoxide d'azote (N_2O) sur la stratégie de répétition au cours de l'apprentissage d'une liste de mots dans un paradigme de rappel libre. Dans l'expérience 1, les sujets apprirent la liste en répétant les mots à haute voix. L'apprentissage fut ralenti et l'analyse des protocoles de pratique enregistrés révela une diminution dans le taux global de répétition. De plus, il y eut une réduction et dans le nombre de mots répétés ensembles et la proportion de mots répétés dans les expositions d'ordre du début de la liste. Dans l'expérience 2, les sujets furent obligés de suivre un protocol de répétition différent, lequel était identique et pour le N_2O et la période témoin sous respiration d'air. Les sujets n'erurent pas de difficulté à suivre ce protocol, mais l'apprentissage était toujours ralenti. Ces résultats démontrent que les stratégies de répétition peuvent être modifiées par la narcose, mais peuvent aussi être manipulées expérimentalement. Ceci est conforme avec l'hypothèse que les variables stratégiques jouent un rôle important dans le modèle opérationel ralenti de la narcose des gaz inertes.

narcose des gaz inertes
apprentissage
stratégie de répétition

Fowler B, Hendricks P, Porlier G. Efectos de la narcosis por un gas inerte en ensayos de estrategia durante un ejercicio de aprendizaje. Undersea Biomed Res 1987;14(6):469–476.—Se realizaron dos experimentos para estudiar los efectos del oxido nitroso (N_2O) al 35% en ensayos de estrategia durante el aprendizaje de una lista de palabras para poder observar el acceso a la memoria. En el experimento 1, los sujetos memorizaban las palabras mientras las repetían en voz alta. El aprendizaje fue lento y al analizar los reportes de los protocolos de los ensayos, se encontró una disminución en la cantidad global ensayada. Así mismo, existió una disminución en el número de las palabras ensayadas juntas y en la cantidad de palabras ensayadas de la secuencia de la lista anterior. En el experimento 2, los sujetos siguieron un protocolo diferente, idéntico al empleado por el control que respiraba N_2O y el que respiraba aire. No tuvieron dificultad para realizarlo, pero el aprendizaje continuaba siendo lento. Estos resultados demuestran que los ensayos de estrategias pueden ser modificados por la narcosis, pero pueden ser manipulados experimentalmente. Esto es congruente con la hipótesis que establece que las variables de las estrategias juegan un papel importante en el modelo de procesamiento lento de la narcosis ocasionada por un gas inerte.

narcosis por gas inerte
aprendizaje
ensayo de estrategia

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